

**Progress Report for Award NAG5-10105 - Year 2001**  
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## **X-ray Spectroscopy of Low-Luminosity Active Galactic Nuclei with XMM**

The measurement of black hole masses in nearby galaxies has transformed our understanding of these systems, allowing us to quantify the relevant scales of power, length and time and explore how the activity of black holes is linked to their environments and to the evolution of their host galaxies.

In this project, Dr. Tiziana Di Matteo has the primary responsibility for developing and investigating theoretical models for the origin of the X-ray emission observed in low-luminosity AGN. Dr. Di Matteo has been involved in interpreting X-ray data and assessing accretion models throughout the project.

### *Accretion flows around low-luminosity AGN*

One of the most outstanding problems in astronomy is why black holes were much more luminous in the early Universe than they are today. I have worked extensively on this problem. Standard accretion theory predicts that the power output from nearby black holes should far exceed their observed luminosities. This lack of activity must be due to either (1) the black holes being somehow starved of fuel or (2) the gas being swallowed into the black holes before it can radiate its energy, as postulated by advection-dominated accretion theory.

The most recent major advance in the study of low-luminosity black holes has been brought about by *XMM* and *Chandra* X-ray observatory. Thanks to the high spatial resolution and improved sensitivity, the new generation X-ray telescopes are now able, for the first time, to detect nuclear X-ray sources in nearby galaxies. We are also measure the central densities and temperatures of the ISM in ellipticals and therefore determine the accretion rates with much greater confidence. In other words, we can now resolve  $L = \eta \dot{M} c^2$ , where  $L$  is the accretion power,  $\dot{M}$  the accretion rate and  $\eta$  the accretion efficiency.

### *The black hole in M87*

The nucleus of M87 (NGC 4486) contains a black hole of mass  $M \sim 3 \times 10^9 M_\odot$  directly determined from *HST* observations (Ford et al. 1995; Harms et al. 1995; Macchetto et al. 1997). It is the most nearby active nucleus with a one sided jet and giant radio lobes. However, the activity displayed by its nucleus is far less than what is predicted if the central black hole was accreting mass from its hot interstellar medium (with a standard radiative efficiency of  $\sim 10$  per cent; see e.g. Fabian & Rees 1995; Reynolds et al. 1996; Di Matteo et al. 2000). M87 is probably the most illustrative case of a low luminosity system otherwise common in nearby galaxies known to contain supermassive black holes (e.g. Magorrian et al. 1998; Ferrarese & Merrit 2000).

There are two possible explanations for the low luminosities of nearby black holes: (a) the accretion occurs at extremely low rates or (b) the accretion occurs at low radiative efficiencies as predicted, for example, by advection dominated accretion flow models (ADAFs; e.g. Rees et al. 1982; Narayan & Yi 1994,1995; Abramowicz et al. 1995). In order to discriminate

between these two possibilities, it is necessary to measure both the accretion rates and nuclear luminosities precisely. Direct measurements of either of these quantities has not been possible with previous X-ray satellites.

*Chandra* observations of the nucleus of M87 has allowed us, for the first time to resolve the thermal state of its hot interstellar medium well within the accretion radius of its central  $3 \times 10^9 M_\odot$  black hole. We have measured gas temperature and density in the accretion region of this system and calculate a Bondi accretion rate of  $\dot{M}_{\text{Bondi}} \sim 0.2 M_\odot \text{yr}^{-1}$ . With *Chandra* we have also measured the X-ray luminosity of the nucleus of M87 to be  $L_x \sim 3 \times 10^{40} \text{ erg s}^{-1}$ . Accretion onto the black hole at the Bondi rate predicts a nuclear luminosity of  $L_B \sim 7 \times 10^{44} \text{ erg s}^{-1}$  for a canonical accretion radiative efficiency of 10%. These new *Chandra* and longer wavelength constraints, provide the most direct evidence that the black hole in M87 is likely to accrete at a much lower radiative efficiency than the canonical value (unless not much of the mass fed into the outer region of its accretion flow reaches the black hole). We show that the Bondi accretion rate is consistent with low-radiative efficiency accretion flow models. Although emission from the base of the jet is important, it still remains possible that a major contribution to the the observed nuclear flux may be due to emission from the accretion flows.

### *Structure formation, X-rays and XMM*

With Rupert Croft (Harvard) and others I have recently investigated the use of cosmological hydrodynamic simulations for predicting the properties of the XRB. A major goal of this work has been to model the soft, diffuse X-ray emission from the warm gas which lies in filamentary structures between galaxies, as well as the emission from the gas in galaxies and clusters themselves, and so help to complete the census of local baryons. We have shown that this diffuse intergalactic gas accounts for a significant fraction of the soft X-ray flux, and that its clustering is significant on scales which should be measurable in angular correlation studies with *Chandra* and *XMM*. We have also modeled the AGN contribution to the XRB and found that within the context of the simulations, black hole accretion implies a relationship between the central black hole mass and bulge velocity dispersion which is consistent with recent observations. The rapidly increasing resolution achievable in hydrodynamic simulations should soon allow us to model the growth of black holes and their feedback on galaxy formation in a self-consistent manner.